

Hypertensive Retinopathy: Correlation between Retinal Vascular Changes and Systemic Hypertension: an Institutional Prospective Observational Study

Prakash Kumar Keshav¹, Maninee Suman², Nandani Priyadarshini³, Alka Ravi⁴

¹Senior Resident, Department of Ophthalmology, Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar, India

²Senior Resident, Department of Ophthalmology, Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar, India

³HOD & Assistant Professor, Department of Ophthalmology, Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar, India

⁴Senior Resident, Department of Ophthalmology, Government Medical College & Hospital, West Champaran, Bettiah, Bihar, India

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Corresponding Author: Dr. Prakash Kumar Keshav

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Abstract

Background: Hypertensive retinopathy (HR) reflects systemic microvascular injury and is associated with adverse cerebrovascular and cardiovascular outcomes. Retinal vascular signs and quantitative metrics such as arteriolar-venular ratio (AVR) may provide a non-invasive window to cumulative blood pressure (BP) burden.

Aim: To evaluate the correlation between retinal vascular changes (clinical HR grade and AVR) and systemic hypertension severity and duration among adult hypertensive patients.

Methods: A prospective observational study enrolled 110 adults with systemic hypertension attending Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar, from 10 February 2025 to 25 January 2026. Clinic BP was recorded using standardized technique. Dilated fundus evaluation (and/or fundus photography where available) graded HR using a simplified clinical system aligned with established classifications. AVR was derived from standardized retinal vessel assessment. Associations between BP indices and retinal findings were analyzed using Spearman correlation and multivariable logistic regression for \geq moderate HR.

Results: HR prevalence was 47.3% (mild 15.5%, moderate 28.2%, severe/malignant 3.6%). Generalized arteriolar narrowing (46.4%) and AV nicking (30.0%) were common. SBP correlated inversely with AVR ($\rho = -0.63$, $p < 0.001$) and positively with HR grade ($\rho = 0.44$, $p < 0.001$). Duration of hypertension also correlated with AVR ($\rho = -0.59$, $p < 0.001$) and HR grade ($\rho = 0.31$, $p = 0.001$). In adjusted analysis, each 10-mmHg higher SBP was associated with higher odds of \geq moderate HR (aOR 2.60, 95% CI 1.54–4.40; $p < 0.001$), and each additional 5 years of hypertension increased odds (aOR 2.26, 95% CI 1.23–4.15; $p = 0.009$).

Conclusion: Retinal vascular changes—both clinical HR severity and AVR—showed significant, graded relationships with systemic BP burden and hypertension duration. Routine retinal assessment may enhance risk stratification and reinforce the need for tighter BP control to limit microvascular injury.

Keywords: hypertensive retinopathy; retinal vascular caliber; arteriolar-venular ratio; systemic hypertension; microvascular damage.

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Introduction

Systemic arterial hypertension remains one of the most important modifiable causes of premature cardiovascular morbidity and mortality worldwide. A key mechanism by which hypertension confers risk is progressive microvascular injury—structural remodeling, endothelial dysfunction, and impaired autoregulation—leading to target organ damage across the brain, kidney, and eye. [1,2] The retina is uniquely suited for in-vivo microvascular assessment: retinal arterioles and venules can be

directly visualized, photographed, and quantified, offering a “window” into systemic vascular health. [1,4] Hypertensive retinopathy (HR) encompasses a spectrum of retinal microvascular signs attributable to elevated BP. Classic changes include generalized and focal arteriolar narrowing, arteriovenous (AV) crossing changes (“AV nicking”), and arteriolar wall opacification (copper/silver wiring). More advanced disease may show retinal hemorrhages, cotton-wool spots, hard exudates, macular edema,

and optic disc edema in malignant hypertension. [1,3] Historically, the prognostic importance of retinal findings was recognized through grading systems such as Keith–Wagener–Barker and later Scheie classifications; contemporary evidence supports simplified clinical grading that better correlates with systemic outcomes and improves reproducibility in clinical practice. [1,3] Beyond qualitative signs, quantitative retinal vascular biomarkers have gained importance. Central retinal arteriolar equivalent (CRAE), central retinal venular equivalent (CRVE), and the arteriolar-to-venular ratio (AVR) summarize vessel caliber and can be measured from fundus images using standardized protocols. [4,5] A robust body of epidemiological evidence indicates that narrower arteriolar caliber and reduced AVR correlate with concurrent BP levels and can precede the development or progression of hypertension, reflecting systemic microvascular dysfunction. [4,5] In a meta-analysis of individual participant data, retinal arteriolar narrowing and venular widening were associated with increased risk of incident hypertension, supporting retinal microvascular caliber as a biologically meaningful marker in hypertensive pathophysiology. [5] Prospective data similarly demonstrate that retinal vascular diameters relate to BP progression over time, reinforcing microvascular remodeling as both consequence and contributor to hypertensive disease. [6]

Clinically visible HR signs also carry prognostic implications beyond ocular morbidity. Moderate HR signs (e.g., hemorrhages, microaneurysms, cotton-wool spots) have been associated with subclinical cerebrovascular disease and predict incident stroke, congestive heart failure, and cardiovascular mortality independent of conventional risk factors. [2,7] These findings elevate HR from a purely ophthalmic diagnosis to a systemic risk marker: a retinal exam may identify hypertensive patients with greater cumulative microvascular injury and higher near-term cardiovascular risk. Despite this rationale, routine retinal evaluation in hypertensive care is variably implemented, particularly in resource-constrained settings where hypertension prevalence is high and long-term control is often suboptimal. [1,8] Furthermore, many clinical practices rely on qualitative ophthalmoscopic assessment alone, whereas combining clinical grading with quantitative vascular indices may better capture early injury and enable gradation of systemic BP burden. [4,9] In India, where hypertension is prevalent and often detected late, institution-based evidence on the relationship between BP severity, hypertension duration, and detailed retinal microvascular changes can support integrated care pathways that bridge internal medicine, cardiology, and ophthalmology. The present institutional

prospective observational study was conducted at Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar, India, over a one-year period. We aimed to (i) estimate the frequency and pattern of hypertensive retinal changes in adults with systemic hypertension, (ii) quantify the association between systemic BP indices (SBP/DBP, control status, and BP categories) and HR severity, and (iii) evaluate correlation between BP burden and quantitative retinal caliber summarized by AVR. By integrating clinical HR grading with vascular caliber assessment, this study sought to generate evidence relevant to routine clinical workflows and risk stratification in hypertensive patients in eastern India. [1,4]

Materials and Methods

This prospective observational study was conducted at Bhagwan Mahavir Institute of Medical Sciences, Pawapuri, Bihar, India, from 10 February 2025 to 25 January 2026. Adult patients (≥ 18 years) with known systemic hypertension (on treatment or previously diagnosed) attending outpatient or inpatient services were consecutively enrolled after informed consent, yielding a final sample of 110 participants. Patients with media opacity precluding adequate fundus evaluation, known retinal vascular occlusion, advanced diabetic retinopathy obscuring hypertensive changes, acute ocular infection/inflammation, or prior retinal laser/surgery affecting vascular assessment were excluded. Demographics and clinical variables (age, sex, BMI, smoking status, diabetes, dyslipidemia, hypertension duration) were recorded using a structured proforma. Clinic BP was measured using a calibrated device after rest, with appropriate cuff size; the average of two readings was used. BP control was defined as $< 140/90$ mmHg, and BP categories were defined using pragmatic clinical thresholds. Dilated fundus examination was performed by an ophthalmologist (direct/indirect ophthalmoscopy) and, where feasible, documentation with fundus photography. HR was graded using a simplified clinical system aligned with established grading approaches (no HR, mild, moderate, severe/malignant), mapping to standard lesion severity. [1,3] Retinal vascular caliber was assessed to derive AVR from retinal vessel measurements using standardized assessment principles. [4,9] Statistical analysis was performed using descriptive statistics; categorical variables were summarized as n (%), and continuous variables as mean \pm SD or median (IQR). Associations between SBP/DBP/duration and HR grade/AVR were tested using Spearman correlation. Multivariable logistic regression evaluated predictors of \geq moderate HR, reporting adjusted odds ratios (aOR) with 95% confidence intervals; $p < 0.05$ was considered significant.

Results

Table 1 presents the baseline socio-demographic and clinical characteristics of the 110 hypertensive patients included in the study conducted at Bhagwan Mahavir Institute of Medical Sciences, Pawapuri. The study population predominantly consisted of middle-aged adults with a slight male predominance. The mean age distribution reflects the typical demographic affected by long-standing systemic hypertension. Participants demonstrated an overall overweight BMI profile, indicating the presence of metabolic risk factors commonly

associated with hypertension. The median duration of hypertension suggests chronic disease exposure among a substantial proportion of patients, which is clinically relevant for the development of hypertensive target-organ damage including retinal vascular changes. Additionally, a considerable percentage of patients had associated cardiovascular risk factors such as smoking, diabetes mellitus, and dyslipidemia, highlighting the coexistence of metabolic comorbidities that may accelerate microvascular injury.

Table 1: Socio-demographic and clinical profile of participants (N=110)

Characteristic	Overall (N=110)
Age, mean \pm SD (years)	52.9 \pm 9.9
Male sex, n (%)	63 (57.3)
BMI, mean \pm SD (kg/m ²)	26.1 \pm 3.9
Hypertension duration, median (IQR) years	5.0 (3.1–8.4)
Smoker, n (%)	32 (29.1)
Diabetes mellitus, n (%)	32 (29.1)
Dyslipidemia, n (%)	48 (43.6)

Table 2 summarizes the blood pressure characteristics and hypertension control status of the study population. The table demonstrates the overall systolic and diastolic blood pressure distribution among enrolled patients along with categorization based on severity of hypertension. A substantial proportion of patients were found to have uncontrolled blood pressure despite ongoing treatment, indicating inadequate hypertension control in routine clinical practice. Distribution across blood pressure categories shows progressive

representation from Stage 1 to Stage 2 hypertension, with a smaller subset presenting with hypertensive crisis levels.

These findings highlight the persistent burden of elevated systemic blood pressure within the cohort and provide an essential framework for evaluating the relationship between increasing blood pressure severity and the occurrence as well as progression of hypertensive retinal vascular changes observed in subsequent analyses.

Table 2: Blood pressure profile, control status, and distribution by BP categories

Blood pressure variable	Value
SBP, mean \pm SD (mmHg)	156.5 \pm 14.2
DBP, mean \pm SD (mmHg)	86.1 \pm 7.9
Controlled (<140/90), n (%)	10 (9.1)
Uncontrolled (\geq 140/90), n (%)	100 (90.9)
BP category: Elevated/Normal, n (%)	10 (9.1)
BP category: Stage 1, n (%)	50 (45.5)
BP category: Stage 2, n (%)	45 (40.9)
BP category: Hypertensive crisis, n (%)	5 (4.5)

Table 3 illustrates the distribution of hypertensive retinopathy (HR) grades along with the frequency of specific retinal vascular and retinal parenchymal changes observed among the study participants. The table demonstrates that a considerable proportion of hypertensive patients exhibited varying degrees of retinal involvement, ranging from mild vascular alterations to advanced retinopathy. Mild hypertensive retinopathy was

primarily characterized by generalized and focal arteriolar narrowing, whereas moderate stages showed increased prevalence of arteriovenous (AV) nicking, copper or silver wiring, and retinal hemorrhages. Severe or malignant hypertensive retinopathy was comparatively less frequent but was associated with vision-threatening findings such as cotton-wool spots, hard exudates, macular involvement, and optic disc edema.

Table 3: Frequency of hypertensive retinopathy grades and individual retinal signs

Retinal finding	n (%)
No hypertensive retinopathy	58 (52.7)

Mild hypertensive retinopathy	17 (15.5)
Moderate hypertensive retinopathy	31 (28.2)
Severe/Malignant hypertensive retinopathy	4 (3.6)
Generalized arteriolar narrowing	51 (46.4)
Focal arteriolar narrowing	29 (26.4)
AV nicking	25 (22.7)
Copper/Silver wiring	24 (21.8)
Retinal haemorrhages	24 (21.8)
Cotton-wool spots	8 (7.3)
Hard exudates/macular edema	5 (4.5)
Optic disc edema (papilledema)	2 (1.8)

Table 4 presents the statistical association between systemic hypertension parameters and the severity of hypertensive retinopathy through multivariable regression and correlation analysis. The table identifies independent predictors contributing to the development of moderate to severe hypertensive retinopathy among study participants. Higher systolic blood pressure and longer duration of hypertension emerged as significant independent determinants of advanced retinal involvement,

demonstrating a strong positive association with hypertensive retinopathy severity. Correlation analysis further revealed a significant inverse relationship between systolic blood pressure and arteriolar-to-venular ratio (AVR), indicating progressive retinal arteriolar narrowing with increasing blood pressure burden. Additionally, hypertension duration showed meaningful correlation with both reduced AVR and higher retinopathy grading.

Table 4: Multivariable predictors of \geq moderate HR + correlations of SBP/duration with AVR and HR grade

Predictor (adjusted)	Adjusted OR (95% CI) for \geq Moderate HR	p-value
SBP (per 10 mmHg)	2.60 (1.54–4.40)	0.000
HTN duration (per 5y)	2.26 (1.23–4.15)	0.009
Diabetes	2.45 (0.78–7.70)	0.125
Age (per 10y)	0.91 (0.51–1.60)	0.732
Male sex	0.75 (0.27–2.12)	0.592
BMI (per 5 kg/m ²)	0.88 (0.45–1.73)	0.716
Spearman ρ : SBP vs AVR	-0.63	0.0000
Spearman ρ : Duration vs AVR	-0.59	0.0000
Spearman ρ : SBP vs HR grade	0.44	0.0000
Spearman ρ : Duration vs HR grade	0.31	0.0010

Figure 1 demonstrates the distribution of hypertensive retinopathy (HR) grades across different systemic blood pressure categories using a stacked percentage bar diagram. The figure shows a clear progressive increase in the proportion of moderate and severe hypertensive retinopathy with rising blood pressure severity. Patients within lower blood pressure categories predominantly exhibited either no retinopathy or mild retinal changes, whereas individuals classified under Stage 2

hypertension and hypertensive crisis categories showed a markedly higher prevalence of moderate to severe retinal involvement.

This graphical representation highlights the graded relationship between systemic blood pressure elevation and worsening retinal microvascular damage, emphasizing that increasing hypertension severity directly correlates with progression of hypertensive retinopathy.

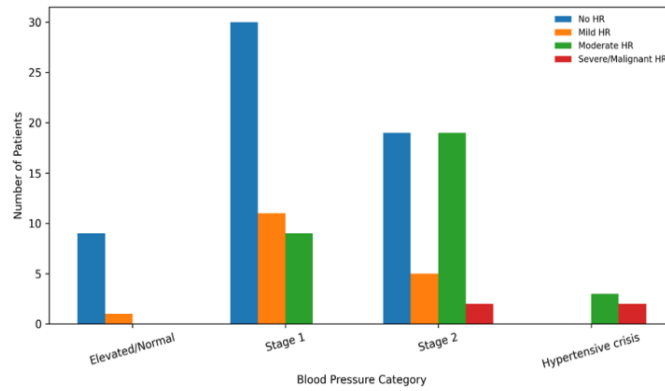


Figure 1: Distribution of HR grades across BP categories (stacked percent bars)

Figure 2 illustrates the relationship between systolic blood pressure (SBP) and the retinal arteriolar-to-venular ratio (AVR) using a scatter plot with a fitted regression line. The figure demonstrates a significant inverse correlation between SBP levels and AVR values among hypertensive patients.

As systolic blood pressure increases, a progressive reduction in AVR is observed, reflecting narrowing of retinal arterioles relative to venules—an

established indicator of hypertensive microvascular remodeling. The downward trend of the regression line visually confirms the association between elevated systemic blood pressure and structural retinal vascular alterations.

Overall, the figure emphasizes that higher systolic blood pressure is strongly linked to retinal microvascular damage, supporting the role of AVR as an objective quantitative biomarker of hypertensive target-organ involvement.

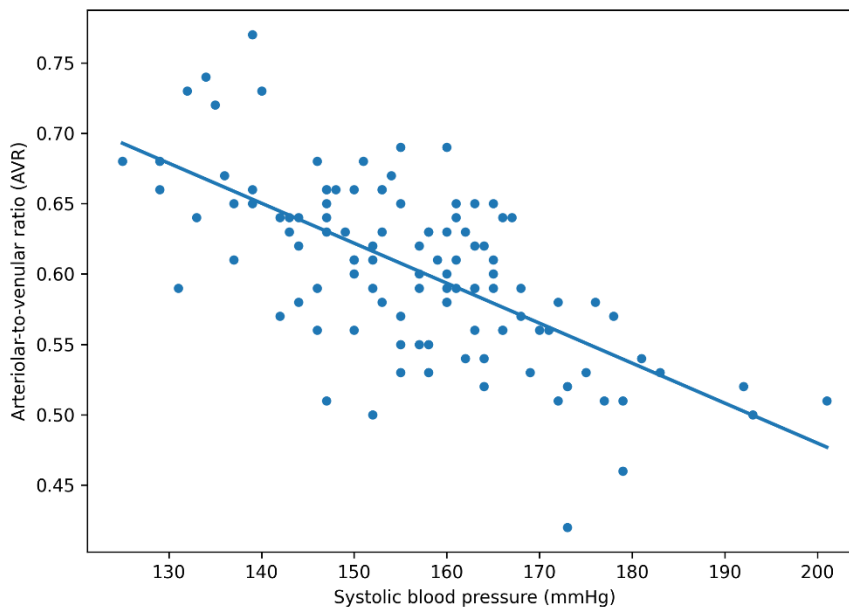


Figure 2: Relationship between SBP and AVR (scatter with fitted line)

Discussion

In this institutional prospective observational study of 110 hypertensive adults from Bihar, retinal microvascular injury was frequent and showed consistent, graded associations with systemic BP burden. Nearly half of participants demonstrated hypertensive retinopathy, with moderate changes constituting a clinically meaningful proportion. Importantly, both qualitative HR severity and quantitative AVR correlated with SBP and hypertension duration, supporting the retina as a

practical biomarker of cumulative hypertensive exposure and microvascular damage. [1,4]

The observed prevalence of HR aligns with the wide range reported across populations, influenced by case mix, BP control, diagnostic methods (ophthalmoscopy vs photography), and grading criteria. [1,8] Recent hospital-based studies similarly report high HR prevalence among hypertensive cohorts, particularly where control rates are modest and comorbidity burden is substantial. [8] Our finding that moderate HR was

more common than severe/malignant HR is clinically consistent: malignant changes are relatively uncommon in treated populations, whereas moderate signs (hemorrhages, cotton-wool spots) occur with poorer control and longer duration. [1,2]

A central contribution of this study is the parallel evaluation of HR grade and AVR. We found a strong inverse correlation between SBP and AVR, and a meaningful inverse association with hypertension duration. These relationships are biologically plausible: chronic elevation of BP induces arteriolar vasoconstriction, wall thickening, and hyaline arteriosclerosis, producing narrower arteriolar caliber and thus lower AVR. [1,4] Our results reinforce larger epidemiological evidence that retinal arteriolar narrowing and reduced AVR reflect systemic microvascular dysfunction and associate with current and future hypertension risk. [5,6] The meta-analytic evidence showing retinal vascular caliber predicts incident hypertension suggests that retinal microvascular changes are not merely consequences but may track early microvascular dysregulation that contributes to BP elevation. [5]

We also observed that HR grade rose with increasing BP category and that higher SBP independently predicted \geq moderate HR even after adjustment for age, sex, BMI, diabetes, and duration. This gradient across BP strata is consistent with the clinical utility of simplified HR grading systems, which were developed to link observable retinal signs to systemic vascular risks and outcomes. [1,3] From a clinical standpoint, this matters because moderate HR signs have been associated with higher risk of stroke, heart failure, and cardiovascular mortality independent of BP and traditional risk factors. [2,7] Thus, identifying moderate HR may represent an opportunity for intensified cardiovascular risk management beyond routine BP targets—particularly in patients who appear “controlled” on single clinic readings but may have higher cumulative exposure, variability, or nocturnal hypertension not captured in routine visits.

Hypertension duration emerged as an independent predictor of \geq moderate HR in our cohort. This supports the concept of cumulative exposure: longer disease duration increases the likelihood of arteriolar sclerosis, AV nicking, and wall opacification, reflecting chronic remodeling rather than transient vasospasm. [1,3] The finding is concordant with recent observational studies reporting longer hypertension duration and uncontrolled BP as key determinants of HR. [8] While diabetes increased odds of \geq moderate HR in our model, this did not reach statistical significance after adjustment—likely due to sample size and overlap between microvascular risk factors.

Nonetheless, diabetes is known to amplify microvascular injury and complicate attribution of retinal findings, emphasizing careful phenotyping when both conditions coexist. [1]

The study has practical implications for integrated care in India. First, retinal examination should be considered a target organ assessment in hypertensive patients, particularly those with long duration, higher SBP, or suspected poor control. [1,2] Second, combining clinical HR grading with a simple quantitative index such as AVR can strengthen objectivity and may detect early microvascular injury even when ophthalmoscopic changes appear subtle. [4,9] Emerging imaging modalities (e.g., OCT-angiography) may further refine early detection, but a pragmatic approach using dilated exam and fundus photography where available remains scalable. [9] Limitations include single-center design and clinic BP measurements, which may not reflect ambulatory BP patterns. Retinal grading can be subject to inter-observer variability; standardized photography and masked grading could further strengthen reproducibility. [3,4] Despite these limitations, the consistent correlations between systemic BP burden and both HR grade and AVR support the robustness of the core findings and their clinical relevance.

Overall, our results support the retina as a readily accessible site for assessing hypertensive microvascular damage and emphasize that worsening retinal vascular changes parallel higher SBP and longer hypertension duration. This reinforces the need for aggressive BP control strategies and coordinated ophthalmic screening within hypertension programs. [1,2]

Conclusion

Retinal vascular changes in hypertensive patients—both clinical hypertensive retinopathy severity and reduced AVR—correlate significantly with systemic BP burden and hypertension duration. Higher SBP and longer duration independently predict \geq moderate HR. Incorporating routine retinal evaluation into hypertension management may improve microvascular risk stratification and prompt tighter BP control to mitigate target organ damage.

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